International Journal of Civil, Structural, Environmental and Infrastructure Engineering Research and Development (IJCSEIERD)
ISSN (P): 2249–6866; ISSN (E): 2249–7978
Vol. 10, Issue 2, Apr 2020, 17–26

NUMERICAL INVESTIGATION OF A REINFORCED CONCRETE DEEP BEAM WITH DIFFERENT OPENING SHAPES

TEKLEWOIN HAILE FITWI

Lecturer, Department of Civil Engineering, Adigrat University, Adigrat, Ethiopia

ABSTRACT

Reinforced concrete building comprises many ducts and channels for sanitary purposes and in order for the accommodation of vital services such as for air ventilation, electricity, internet, and computer networks. Hence, these services may rarely obligate openings of structural components of a building (Beam/deep beam, slab, column, etc.). In this study, the effect of various opening shapes with varying locations on the performance of reinforced concrete deep beam was studied. A finite element analysis software Abaqus CAE was used to simulate simply supported reinforced concrete deep beams consisting of openings. For calibration of the finite element software, an experimental test of a reinforced concrete deep beam was used. The reinforced concrete beam model was created using C3D6, T3D2 elements representing both linear and non-linear behavior of concrete and reinforcing bar respectively. The vital assumption is that the contact between the concrete and the reinforcement is established by an embedded region and there is full displacement compatibility between the reinforcement steel and the concrete thus no bond slippage occurs. Thus, it's found out that the location of openings is more critical than the opening shapes. A circular opening has shown better shear resistance than the square one irrespective of their location.

KEYWORDS: Reinforced Concrete Deep Beam, Abaqus CAE, C3D6, T3D2 & Finite Element Analysis

Received: Feb 03, 2020; **Accepted**: Feb 23, 2020; **Published**: Mar 11, 2020; **Paper** Id.: IJCSEIERDAPR20203

Original Article

INTRODUCTION

Quite a lot of studies have been done on web openings of reinforced concrete beams such as [2] carried out a study intended at examining the outcome of various web openings along the span of a reinforced concrete beam on the flexural resistance. An overall of nine rectangular beams were investigated. The anticipated failure mechanism rendering to bending moment-axial force interaction diagrams. Longitudinal reinforcements and stirrups adjacent to the hole and short stirrups in the chords avoided beam-form and frame-form shear failures. The extent of the plastic failure mechanism enlarged in the occurrence of various openings compared to beams with only one opening. [4], well thought-out a reinforced concrete beam with large rectangular hole with an action of pure torsion. It is concluded that the torsional resistance and stiffness of a reinforced concrete beam reduces with rising opening dimensions nonetheless look to be to some extent affected by its eccentricity. The beams fail by the development of a mechanism with four hinges, one at each turning of the hole.

[5], carried out researches on optimum opening form in reinforced concrete beams with an application of pure bending. Reducing the stress buildup around these openings is a vital assumption in engineering analysis and design. To reduce the stress buildup is to differ the opening form while waiting for the optimized form with least stress concentration factor is attained within definite geometric constraints and loading configurations. [6], observed an experimental research on reinforced concrete continuous beams with a large transverse hole. Failure of the

reinforced concrete beam arises by the development of a mechanism, and the two-hole ends characterize the most susceptible positions for the formation of a plastic hinges. The resistance and stiffness of the beam reduces with a growth of either in the span or depth of the hole. [7] showed a numerical method, built on the energy principles, to guess the critical lateral-buckling action of long, doubly symmetric reinforced concrete beams including un-reinforced web holes. The critical actions assessed numerically are associated with the experimental results. The research illustrates a good agreement between the numerical and experimental result.

[8], observed a reinforced concrete beam with hole supported and unsupported with fiber reinforced polymer (FRP) sheets. An experimental study on the performance and resistance of a reinforced concrete beams with shear holes was investigated. The existence of an un-strengthened hole in the shear region of a reinforced concrete beam reduces its resistance. The use of FRP sheets to strengthen the extent around holes may retrieve the resistance of the reinforced concrete beam for comparatively small holes.[3] illustrates that resistance of reinforced concrete deep beams with holes attained by analysis of finite element software illustrates a good agreement with the experimental data, and it is determined that the hole positions has much more consequence on the structural resistance than the hole form. Reinforced concrete deep beam holes may be of different forms, dimensions and are generally positioned near to the supports where shear is the major factor. Reinforced concrete building involves many ducts and channels for sanitary purposes and as for the accommodation of vital services like for air ventilation, electricity, internet, and computer networks. Sometimes these services may obligate openings of structural components of a building, for instance, a reinforced concrete deep beam. openings in reinforced concrete deep beams may permit the installation of these services. Consequently, the effect of various opening forms with varying locations on the resistance of reinforced concrete deep beams needs to be studied.

GENERAL OBJECTIVE

Typically, the objective of this research is to examine the outcome of various opening shapes on the resistance of reinforced concrete deep beams.

Specific Objectives

- To examine the effect of different opening profiles by fixing opening dimensions and varying opening locations on the shear carrying capacity of the deep beams.
- To critically compare the effect of circular opening to that of equivalent square opening profile.
- To determine the opening location this will have the least negative impact on the reinforced concrete deep beams load-carrying capacity.

Scope of the study

The primary focus of this study was to know the outcome of circular and square openings with a varying location in the shear region of a reinforced concrete deep beam and to find the location which will have the least negative impact on the resistance of reinforced concrete deep beams. This study was limited to a reinforced concrete deep beam type with only two opening shapes. The study used calibrated finite element software Abaqus CAE as the main source of data and other major sources comprises of prior studies done on this area.

METHODOLOGY

Source of Data and Collection Method

Table 1: Cross-Section Details of (Ning Zhang, 2007) RC Deep Beam

Beam Name	b (mm)	h (mm)	d (mm)	Supporting Plate and width of Loading (mm)	Bottom Reinforcement (mm^2)	Web Reinforcement (mm^2)	a/d	f_c' (Mpa)
1DB100bw	230	1000	904	150	2502(2T25+4T22)	942(6R10)	1.1	28.7

The source of data that were employed was predominantly of primary in nature, specifically reinforced concrete beam models were analyzed by finite element software Abaqus CAE. For secondary data, earlier research papers, scientific journals, magazines of civil engineering, books, and the internet were used. The data collection was done randomly, giving more emphasis with respect to relevance and validity to the study area including acceptance within the scientific society.

Tools and Techniques

The foremost experimental tool employed in this study was computer software Abaqus CAE, a general-purpose finite element modeling package. The technique adopted for this study is shown in the flow diagram which yielded the desired result.

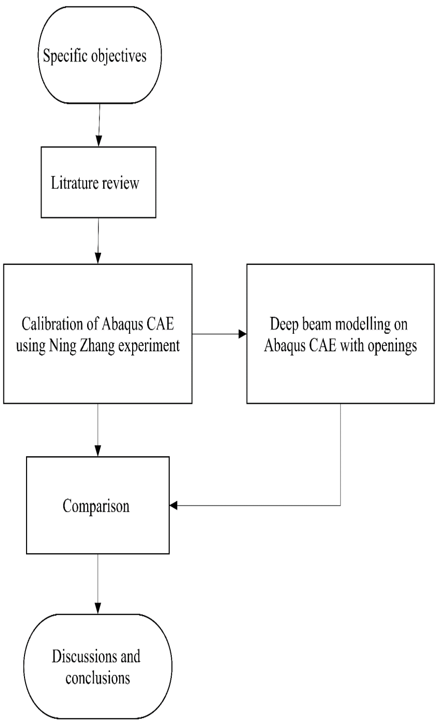

Figure 1: Work Flow Chart.

Table 2: Material Details of (Ning Zhang, 2007) RC Deep Beam

Types of Reinforcement	Nominal Yield Stress f_y (MPa)	Nominal Ultimate Stress f_u (MPa)	Young's Modulus $E(GPa)$
R10	455	522	190
T22	520	614	197
T25	555	639	193

Table 3: Calibrated Parameters

Initial Arc Length Increment	Minimum Arc Length Increment	Maximum Arc Length Increment	Approximate Global Size		Element Type	
			Concrete	Rebar	Concrete	Rebar
0.001	1.00E-20	1.00E+20	40	20	C3D6	T3D2
Concrete Damage Plasticity Parameters						
Dilation angle	**Eccentricity**	**fb0/fc0**	**K**	**Viscosity parameter**		
37	0.1	1.16	0.6667	0.00001		

Calibration of finite Element Analysis Software

Experimental reinforced concrete deep beam test was used to calibrate finite element analysis software Abaqus CAE. Calibrated parameters are shown in table 3. Cross-sectional and material detail of experimental data is shown in tables 1 and 2 respectively. In this simply supported deep beam analysis, the plasticity model of concrete damage in Abaqus CAE has been introduced thoroughly. Finally, the results of the experiment and the Abaqus CAE analysis were compared.

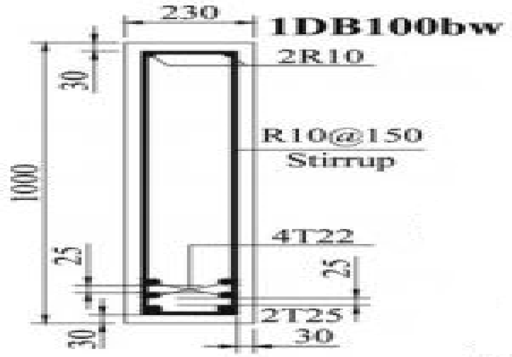

Figure 2: (Ning Zhang, 2007) RC Deep Beam Cross-Section.

The test setup used to perform the experiment is shown below. Simply supported RC deep beam were subjected to two-point loadings with the load-control mode is adopted.

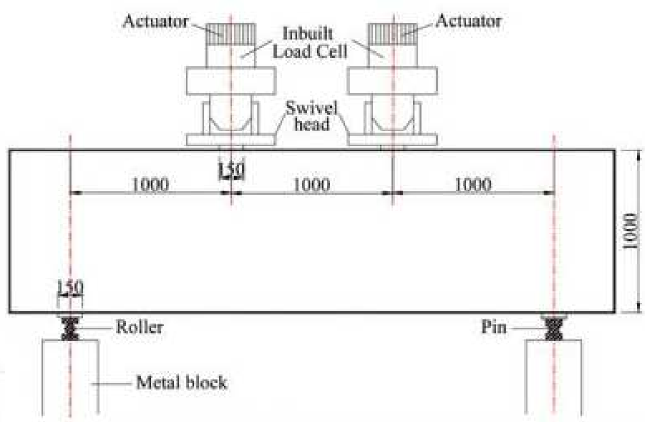

Figure 3: Typical Test Setup for Large RC Deep Beams of (Ning Zhang, 2007) Experiment.

Material and cross-section details of [1] RC deep beam were used to model on finite element software Abaqus CAE. The contact between the reinforcing steel cage and the concrete is known as an embedded region constraint. This type of constraint lets you embed a region of the model within a "host" part of the model or within the whole model, tying

the displacements of each embedded node to the displacements of the surrounding nodes [9]. The solution of the finite element equations is performed using the arc length convergence algorithm method.

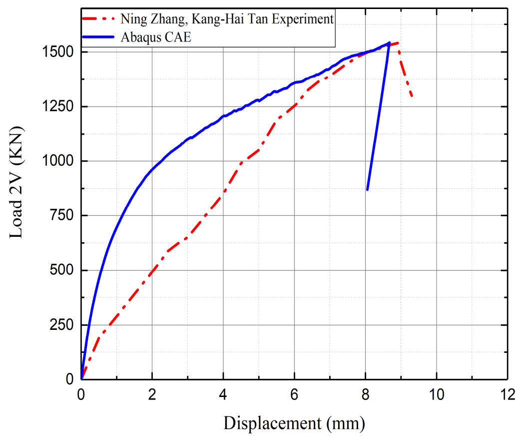

Figure 4: Load vs. Displacement.

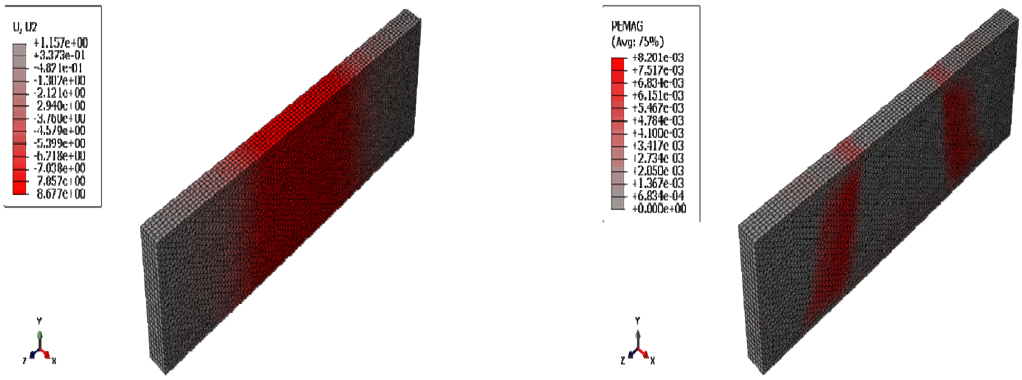

Figure 5: Finite Element Analysis Outputs.

It can be observed from the figure that finite element analysis software Abaqus CAE and experimental data has shown a good agreement in terms of failure load, failure mode (shear compression) and mid-span displacement as well.

RESULTS AND DISCUSSIONS

The simulated finite element model of experiment [1] was used to study the effect of circular and square opening shapes on the resistance of reinforced concrete deep beam by varying opening location with a fixed dimensional area (A=15393.804 mm^2) as shown in figure 6. In order to use efficient modeling techniques, the symmetry boundary conditions were employed. The ratio of the span to the overall section depth is less or equal to 3 (L/D $\leq$ 3) [10]). Hence, the simulated finite element model beam is classified as a deep beam.

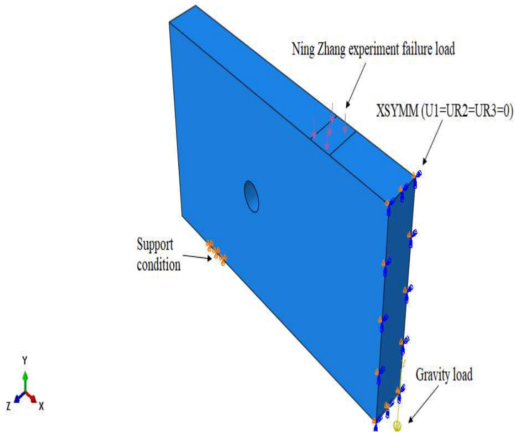

Figure 6: Symmetry Finite Element Model.

Circular Opening

The simulated finite element model is used in providing a circular opening with a diameter of 140 mm by varying L_1 and L_2 as shown in figure 7. Shear failure load versus L_1 and L_2 is shown in figure 8 & 9 respectively.

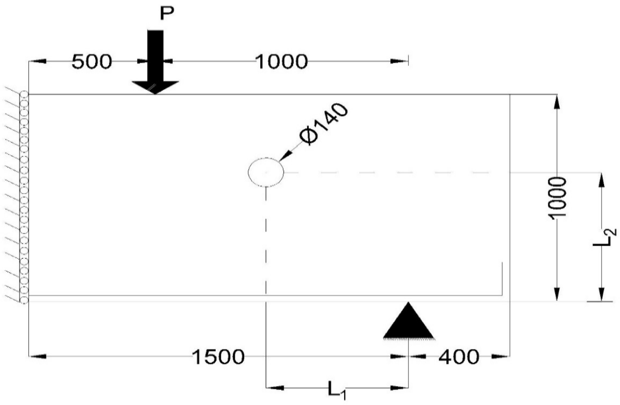

Figure 7: Circular Opening.

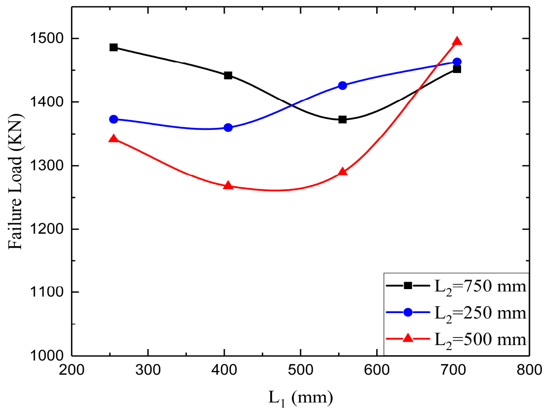

Figure 8: Failure Load vs. L_1.

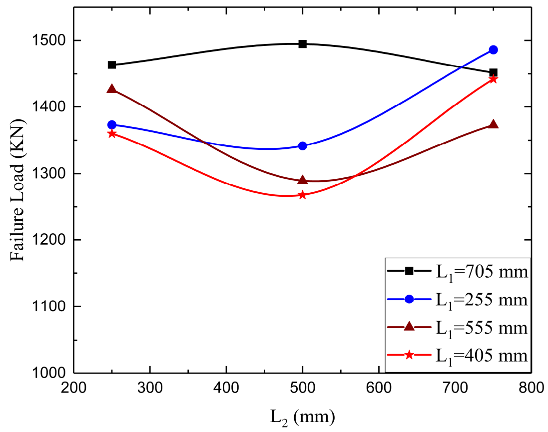

Figure 9: Failure Load vs. L_2.

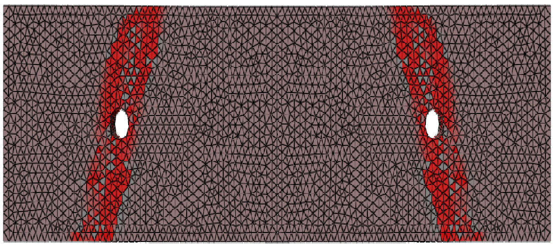

Figure 10: Circular Opening Along Compression Strut.

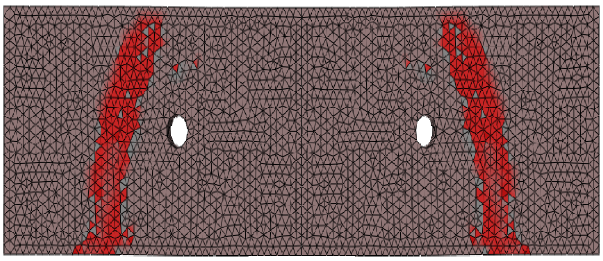

Figure 11: Circular Opening Away from Compression Strut.

Square Opening

Square opening with a dimension of (124.072 mm X 124.072 mm) is considered by varying L_1 and L_2 as shown in figure 12. Shear failure load versus L_1 and L_2 is shown in figure 13 & 14 respectively.

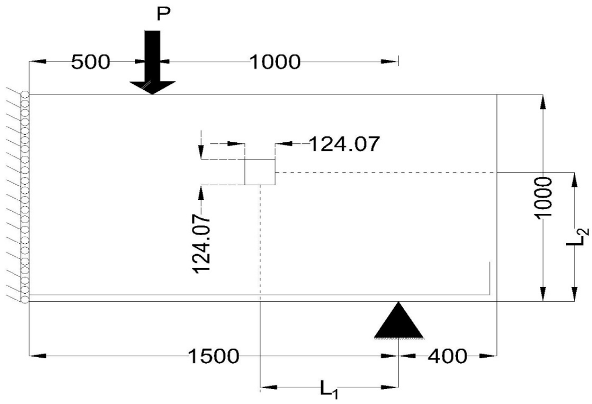

Figure 12: Square Opening.

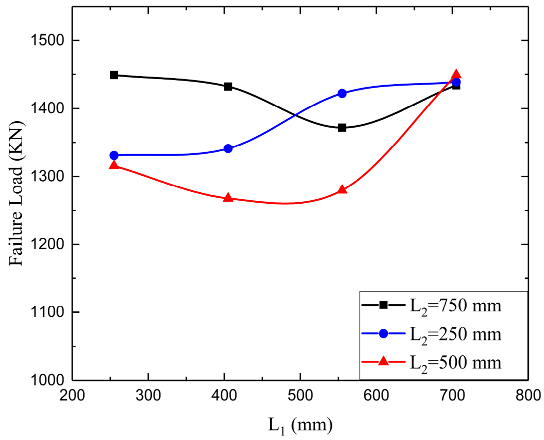

Figure 13: Failure Load vs. L_1.

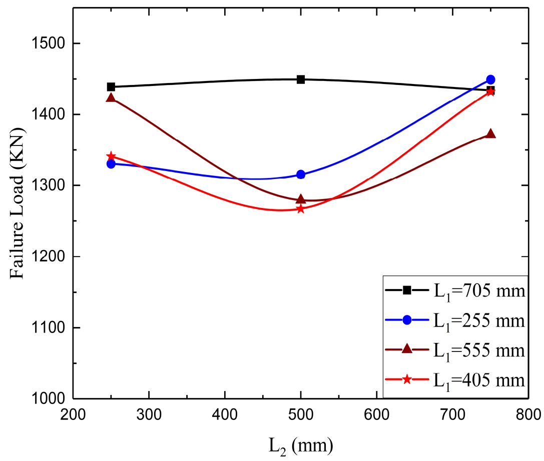

Figure 14: Failure Load vs. L_2.

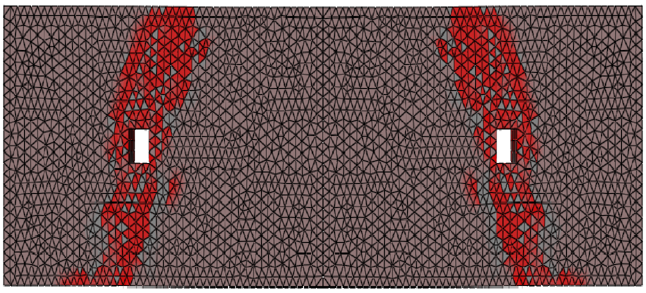

Figure 15: Square Opening along Compression Strut.

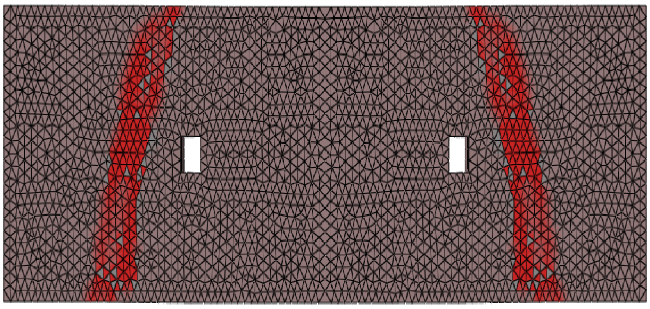

Figure 16: Square Opening Away from Compression Strut.

CONCLUSIONS

From the numerical study, the following conclusions have been drawn.

- The finite element analysis software Abaqus CAE has shown good agreement with experiment [1] in terms of failure load, failure mode (shear compression) and mid-span displacement.
- The symmetry boundary conditions were the efficient modeling techniques with regards to reducing the analysis run time and memory required without affecting the result.
- The opening location which has the least negative impact on the reinforced concrete deep beams is away from the compression strut in the middle center and close to the upper corners of the deep beam.
- Opening regardless of its shape along the compression strut has shown low shear resistance and disturbed load path patterns.
- The circular opening shape has shown a better shear resistance than the square opening shapes.

REFERENCES

1. *Size effect in RC deep beams: Experimental investigation and STM verification. Ning Zhang, Kang-Hai Tan. 2007, Engineering Structures, pp. 3241-3254.*
2. *Flexural Behavior of RC Beams with Regular Square or Circular Web Openings. B Aykac, I Kalkan, S Aykac, and Y E Egriboz. 2013, Engineering Structures, pp. 2165–2174.*
3. *Effects of Opening Shape and Location on the Structural strength of R.C Deep beams with openings. Alsaeq, Haider M. 2013, World Academy of Science, Engineering and Technology International Journal of Civil and Environmental Engineering, pp. 494-499.*
4. *Torsion Tests of Reinforced Concrete Beams with Large Openings. M. A. Mansur, S K Ting and S Lee. 1983, J. Struct. Eng, pp. 1780-1791.*
5. *Optimum Hole Shapes in Beams under Pure Bending. Naik N, Kumar R and Rajaiah K. 1986, J. Eng. Mech., pp. 407-411.*
6. *Piecewise Linear Behavior of Rc Beams with Openings. M A Mansur, K. H. Tan, Y F Lee, and S L Lee. 1991, J. Struct.Eng., pp. 1607-1621.*
7. *Lateral Buckling of Doubly Symmetric Beams Containing Openings. Shanmugam, V Thevendran and N E. 1991, J. Eng. Mech., pp. 1427-1441.*
8. *Design Against Cracking at Openings in Reinforced Concrete Beams Strengthened with Composite Sheets. H A Abdalla, A M Torkey, H A Haggag, and A F Abu-Amira. 2003, Composite Structures, pp. 197–204.*
9. *Abaqus 6.14 Abaqus User's Guide. RI, USA: s.n., 2014.*
10. *ES EN 1992-1-1:2015, Design of Concrete Structures. Addis Ababa, Ethiopia: s.n., 2015.*

AUTHOR PROFILE

Teklewoin Haile Fitwi (M.Sc. in Structural Engineering), Lecturer at Civil Engineering Department of Adigrat University, University Street, Adigrat, Tigray, Ethiopia

I completed my academic credentials with Bachelor of Science in Civil Engineering (2014) from Mekelle University, Ethiopia and Masters of Science in Structural Engineering (2018) from Mekelle University, Ethiopia and I affiliated to Adigrat University as a full-time lecturer.